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Energy Dissipation on Block Ramps with Large Scale Roughness

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Abstract: *Block ramps represent a steep sloped short section of a channel provided with large roughness and used as grade stabilization structures. Experimental study on block ramp with macro roughness has been carried out in this paper for studying the water surface profile over the ramp and also for quantification of energy loss. Measured water surface profiles over ramps of various slopes reveal that steeper slope is reigned mainly by non-uniform flow, however, uniform flow occurs on major part of the ramps for relatively less steeper slopes. The energy dissipation over block ramp with large roughness is more for higher size of the boulders. The energy dissipation computed using existing equation is in good agreement for low slope (1V:9.87H), while it deviates from the observed values for higher slopes (1V:6H) and (1V:3H). Energy dissipation per unit length of the ramp increases with increase in the ramp slope.*

Keywords: *Block ramp, Energy dissipation, Water surface profile, Roughness, Boulder, Gradation.*

1. INTRODUCTION

Block ramps represent a steep sloped short section of a channel provided with large roughness in form of boulders and passes flow from higher elevation to lower by dissipating the energy. They are a common natural solution to bypass large steps in river beds and are used in rivers as grade stabilization structures. They are also used downstream of low height hydraulic structures like gabion weirs, check dam, trench weir etc. as energy dissipator. They have a unique characteristic of preserving the ecological balance in a river restoration project as it does not change morphology of the river appreciably.

Under the subcritical approach flow condition, the flow is critical at the beginning of the ramp while at toe it is likely that flow shall be super-critical and a weak hydraulic jump shall occur, which needs a small stilling basin. Flow over the ramp may be tumbling or skimming depending on the flow rate over it. Tumbling flow occurs at low discharge and flow tumbles over the macro-roughness, however, under high discharge, flow skims over the boulders at super-critical velocity and it is called skimming flow. Flow over ramp as skimming is hydraulically similar to that over a stepped chute or a stepped spillway. Block ramps may be classified as shown in Fig. 1.

Block ramps often ensure the morphological continuity of the stream and pose a limited environmental impact. They modify the longitudinal profile of a river and, at the same time, guarantee correct biological exchanges i.e., can be used for fish passage design. Block ramps have a good compatibility with the surrounding landscape. In addition to functional quality and economic terms, the economic benefits could cost half the traditional works.

Various studies have been conducted to study the various aspects of the block ramps. Pagliara and Chiavaccini (2006a) studied energy dissipation on block ramp with base material while Pagliara and Chiavaccini (2006b) studied energy dissipation on reinforced block ramps. Peruginelli and Pagliara (2000) studied the energy dissipation on block ramps with regard to skimming flow condition while Pagliara et al. (2008) studied flow over block ramp under submerged flow conditions. Pagliara and Lotti (2009) studied the effect of permeable bed on energy dissipation. Ahmad et al. (2009) studied the effect of staggered arrangement of boulders on energy dissipation. Ghare et al. (2010) presented a mathematical model which correlates the representative bed material size of block ramp with the step height of stepped chute using multiple regression analysis so that, the findings of stepped chutes can be used for the design of block ramp system

Pagliara and Chiavaccini (2006a) carried out runs for block ramps with a slope ranging between 1V:4H and 1V:12H in three different flumes: the first 0.25 m wide, the second 0.35 m, and the last one 0.8m, in order to evaluate the scale effects. The grain size was chosen in order to have a large range of roughness conditions and a uniform coefficient of bed material, expressed by the ratio between d_{60} and d_{10} close to 1 (where d_x, x percent of material having size less than d). Based on the experimental study, they proposed Eq. (1) for energy dissipation on block ramps for various roughnesses as defined in Table 1.

$$\Delta E_r = A + (1 - A)e^{(B+CS)h_c/H} \tag{1}$$

In which, relative energy loss ΔE_r = $\Delta E/E_0$, (ΔE = Energy at upstream E_0 – Energy at tail E_1), S = ramp slope; h_c = critical depth of flow; H = height of ramp; A, B, C are the parameters that depend on the scale roughness conditions of the ramp and given in Table 1.

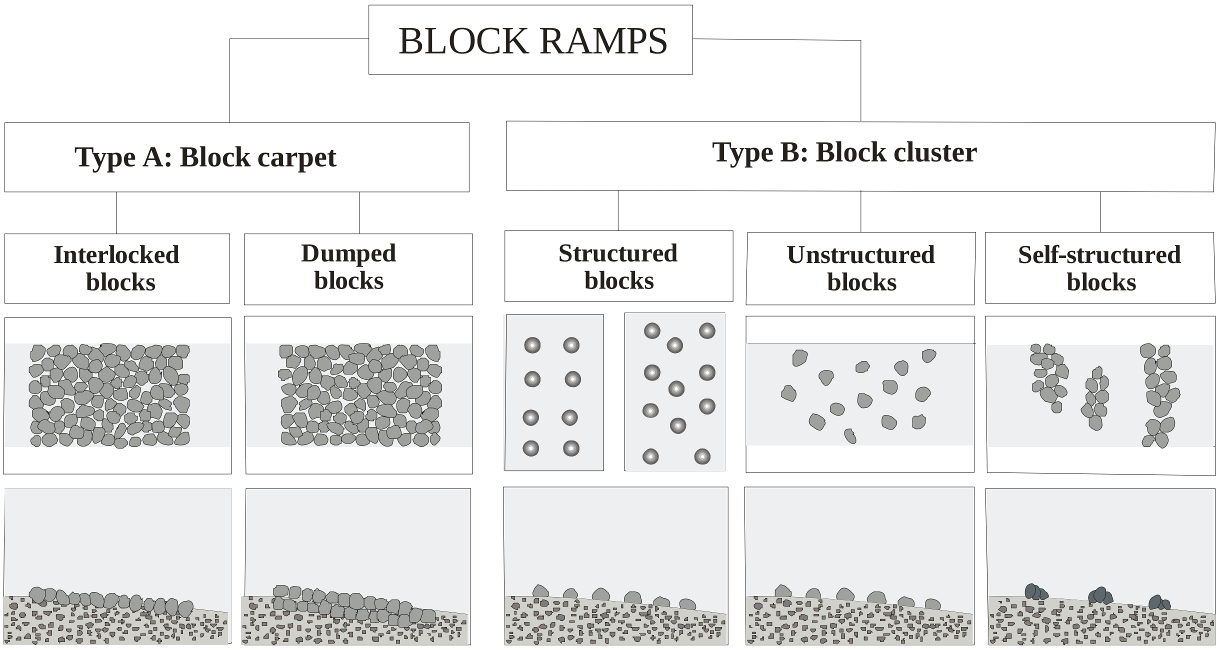


Figure 1 - A morphological and structural classification of block ramps (adapted after Tamagni et al., 2011)

Table 1 Roughness conditions and values of parameter of Eq. (1)

Roughness condition	h_c/d_{50}	A	B	C
Large scale roughness (LR)	h_c/d_{50}< 2.5	0.33	-1.3	-14.5
Intermediate scale roughness (IR)	2.5 < h_c/d_{50}< 6.6	0.25	-1.2	-12.0
Small scale roughness (SR)	6.6 < h_c/d_{50}< 42	0.15	-1.0	-11.5
Smooth ramp	h_c/d_{50} > 42	0.02	-0.9	-25.0

Energy dissipation on the ramps depends on various parameters like height of the ramp, size, slope, and gradation and arrangement of the boulders on the ramp. Various effects like submergence, roughness, boulder arrangement in row, random and staggered have been investigated by various investigators. Stability of boulder ramp has also been investigated for the effective design of block ramp structure. In the present study, effect of boulder gradation on energy dissipation of flow has been studied through experimentation for interlocked blocked - Type A block ramp.

2. EXPERIMENTAL WORKS

The experiment was conducted in the Hydraulic laboratory of Department of Civil Engineering, IIT Roorkee, India on a 0.83 m wide rectangular ramp. The height of the ramp was kept equal to 0.70 m, while the lengths of the ramps were 6.21 m, 4.20 m and 2.10 m. The experiment was performed on three ramp slopes i.e., 1V:9.87H, 1V:6H and 1V:3H. A broad crested weir of the width 0.20 m was provided upstream of the ramp. A tank of size 1.85 m ×1.1m×1.75m was provided upstream of ramp in which the water was supplied from an overhead tank through two supply pipes. Grid wall and wave suppresser were provided in the tank upstream of the broad crested weir to ensure smooth entry of water to the broad crested weir. A solid triangular concrete sill at the toe of the ramp was provided to enhance the stability of ramp. The plan and section of the experimental set up are shown in Figs. 2a and 2b, respectively. Several holes were provided in middle of the ramp along its length and these holes were connected with piezometric tubes for the measurement of piezometric head at each hole. The piezometric head was divided by $\cos\theta$ (θ = ramp slope) to obtain depth of flow at each hole location. Discharge over the ramp was measured by measuring the discharge in each two supply pipes using ultrasonic flow meter.

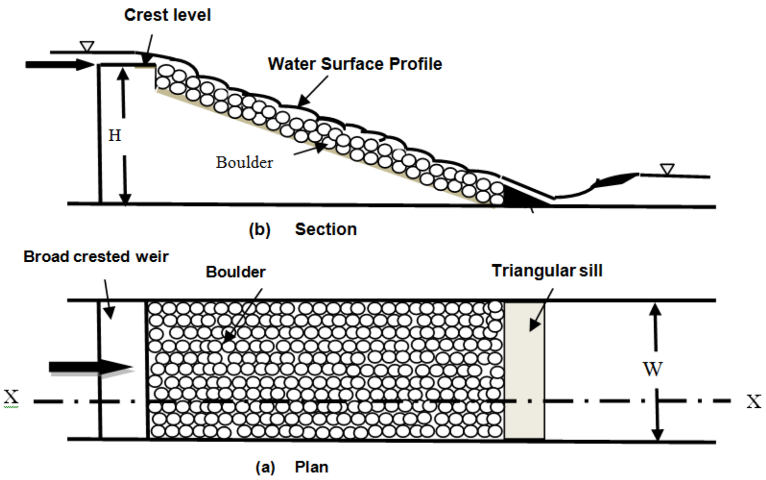


Figure 2 - Schematic drawing of the experimental model

The experimental tests were carried out on nine different gradations of the boulders. Using volume displacement method, the size of each boulder was calculated and after that discrete approach was used to arrive at boulder distribution function which can be defined as

$$F_d(d) = m/(N+1) \tag{2}$$

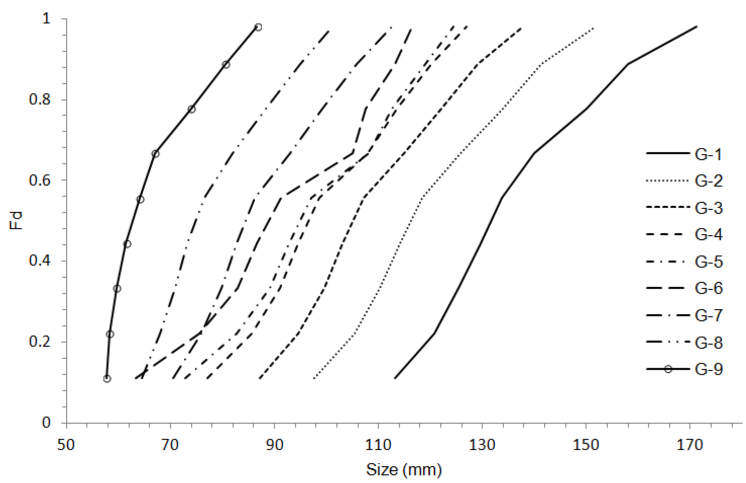


Figure 3 – Gradation of the boulders used in the experimental study

Where, *m* is the ranking number and *N* is the number of boulders taken in the sample. The distribution patterns of all the nine gradations were thus obtained and the same were plotted with the size of boulders to arrive at boulder distribution chart as shown in Fig. 3. Photographic view of gradation G-1, G-6 and G-9 are shown in Fig. 4 as illustration. Different sizes of gradation are given in Table 2.

Figure 4 - Photographic view of gradations G-1, G-6, & G-9

Table 2 Boulders gradation used in the experimental study

Gradation	G-1	G-2	G-3	G-4	G-5	G-6	G-7	G-8	G-9	Fd
d_{10}	113.25	97.71	87.17	77.18	72.75	63.32	70.51	64.40	57.72	0.11
d_{20}	120.72	105.42	94.64	85.58	82.78	75.45	75.88	67.90	58.20	0.22
d_{30}	125.40	110.32	99.50	91.00	89.09	82.92	79.76	70.84	59.60	0.33
d_{40}	129.60	114.19	103.08	94.49	92.72	86.65	82.64	73.30	61.45	0.44
d_{50}	133.80	118.32	107.09	98.59	97.07	91.30	86.15	76.44	64.00	0.56
d_{65}	140.00	125.70	114.90	107.90	108.20	105.00	93.00	81.90	67.00	0.67
d_{84}	150.00	133.90	122.05	113.55	112.65	107.50	99.25	88.30	74.00	0.78
d_{90}	158.05	141.34	129.12	120.16	118.94	113.25	105.88	94.87	80.60	0.89
d_{100}	171.12	151.76	137.85	126.93	124.46	116.52	112.51	101.07	86.65	0.98
d_{90}/d_{10}	1.24	1.29	1.32	1.4	1.487	1.66	1.32	1.3	1.16	

Experiments were performed for all the nine gradations G-1 to G-9 of the boulders on ramp slopes 1V:9.87H; 1V:6H and 1V:3H. In all, 27 arrangements were investigated in the present study with 9 gradations of boulders for each slope. The ranges of the collected data in the present study are given Table 3.

Table 3 Ranges of the data in the present study

Parameter	**Range**
Discharge (m^3/s)	0.014 - 0.106
Boulder size (mm)	57.72- 171.124
Slope, *S*	1V:9.87, 1V:6H, 1V:3H
Ramp height, *H*	0.70 m
Length of Ramp, *L*	2.1-6.21m

3. ANALYSIS OF DATA

3.1. Water Surface Profile over Block Ramp

Measured water surface profiles over the ramp for three ramp slopes i.e., 1/9.87; 1/6; and 1/3 and for each slope three discharges are shown in Fig. 5, as illustration. Water surface profiles may be divided into three parts i.e., (a) initial region, (b) uniform region, and (c) tail region. In the initial region, the flow accelerates which is accomplished by lowering the water level. Initial region is followed by uniform region which is characterized by constant depth of flow. However, flow is again non-uniform at the tail end. For ramp slopes S=1/9.87 and 1/6; uniform flow region is extended to large part of the ramp, however, it is limited for the ramp slope 1:3. It may be concluded that steeper slope is reigned mainly by non-uniform flow.

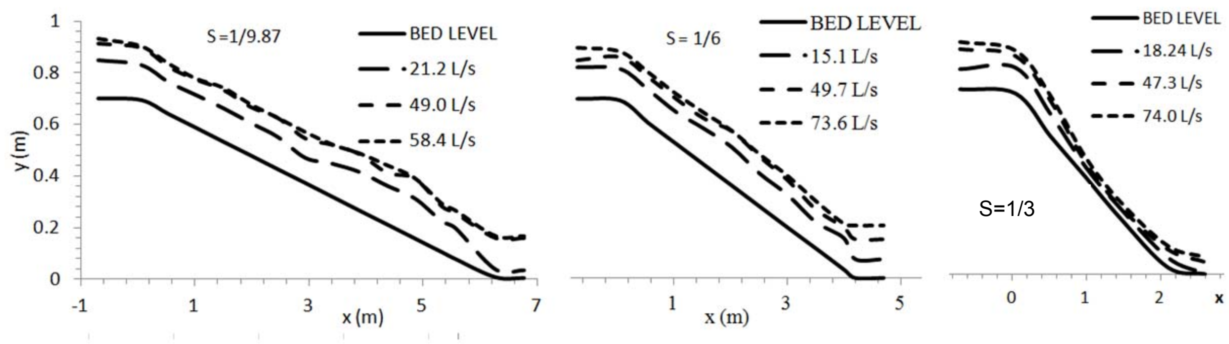


Figure 5 - Water surface profile over block ramps

3.2 Energy Dissipation

3.2.1. Variation of Relative Energy Dissipation with Critical Depth

Energy dissipation of flow over the ramp were calculated for each run using measured water levels in the supply tank and tail water depth, discharge, and height of the ramp. Variation of ΔE_r with h_C/H for ramp having slope 1V:9.87H for all the nine gradations is shown in Fig. 6. Computed relative energy dissipation using Eq. (1) for different h_C/H and ramp slope 1V:9.87H is also shown in Fig. 6. It to be noted that roughness of the gradations decreases from G-1 to G-9. Fig. 6 reveals that energy dissipation is high for G-1 gradations and decreases with decrease of size of the boulders. Energy dissipation is high for low h_C/H due to macro-roughness while it is less for high h_C/H due to cushing of the macro-roughness.

Pagliara and Chiavaccini (2006a) classified roughness into three types viz. small scale roughness (SR), intermediate roughness (IR) and large scale roughness (LR) on the basis of h_c/d_{50} criterion. As per their observations, the energy dissipation increases with the increase in roughness i.e. the small scale roughness (SR) being least effective and LR; being most effective in energy dissipation. The data collected in the present study fall in the range of LR type. Therefore in Eq. (1), A=0.33; B= -1.3 and C=-14.5 have been adopted for the computation of the energy dissipation.

Variation of ΔE_r with h_C/H for ramp having slope 1V:6H for all the nine gradations is shown in Fig. 7. Energy dissipation decreases with decrease size of boulders. Pagliara and Chiavaccini (2006a) equation is in good agreement with the global behavior of experimental data, even if differences between computed and observed values can be noted due to boulders gradation.

Variation of ΔE_r with h_C/H for ramp having slope 1V:3H for all the nine gradations is shown in Fig. 8. Energy dissipation decreases with decrease size of boulders. The Pagliara and Chiavaccini (2006a) equation under-estimate energy for ramp slope 1V:3H in particular for higher h_c/H.

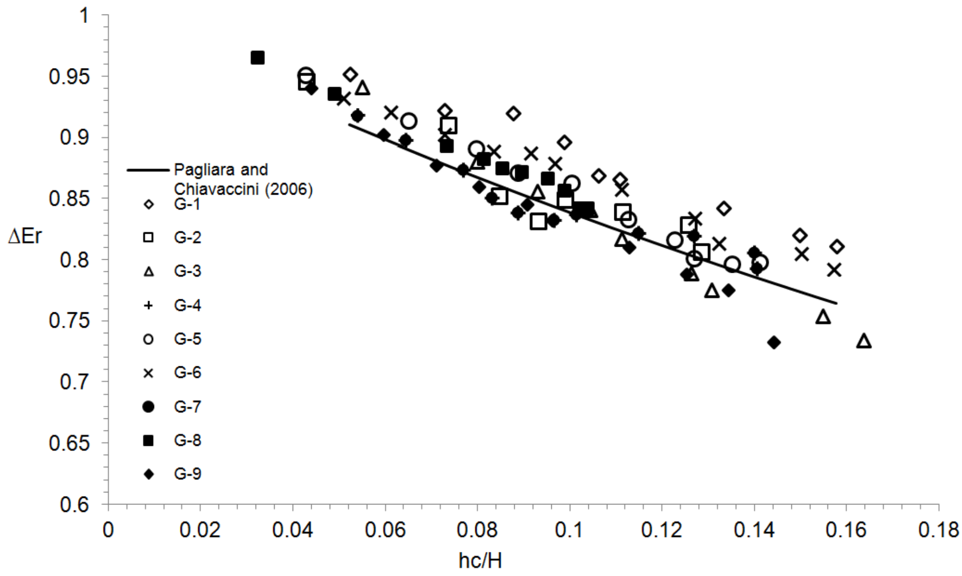


Figure 6 - Variation of relative energy dissipation with h_c/H for ramp slope 1V:9.87H for all gradations

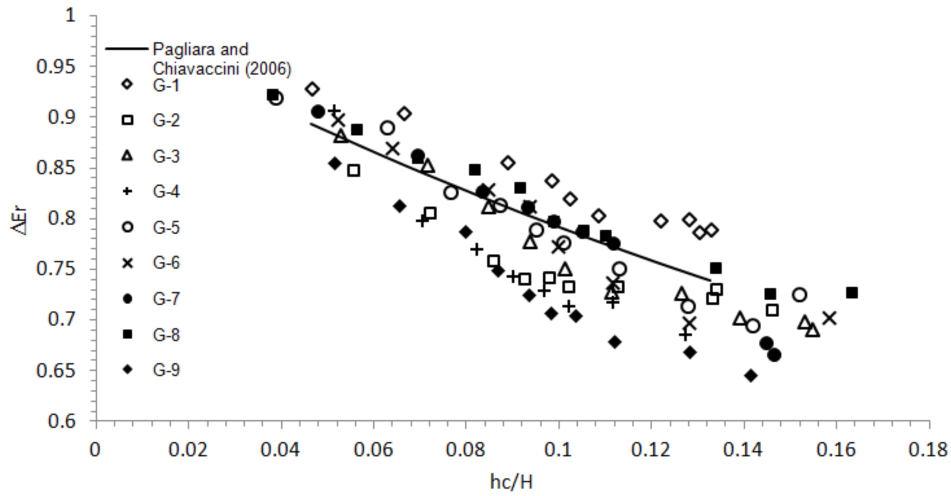


Figure 7 - Variation of relative energy dissipation with h_c/H for ramp slope 1V:6H for all gradations

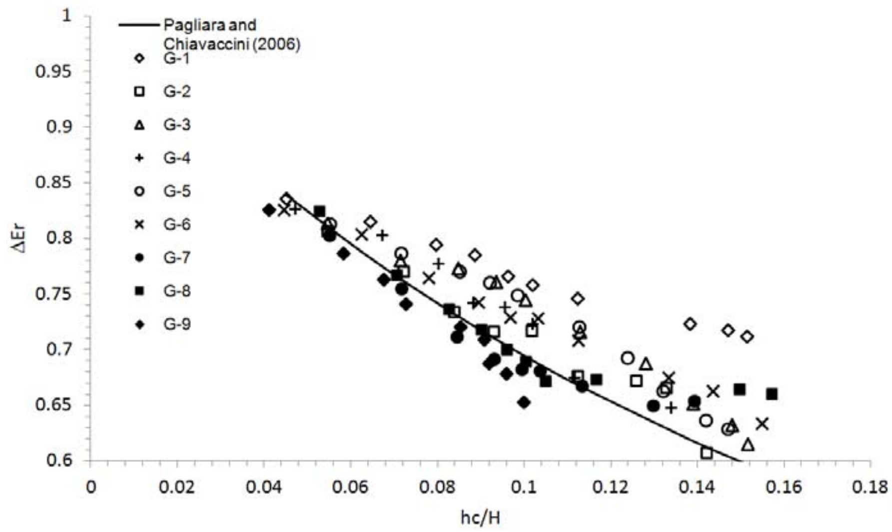


Figure 8 - Variation of relative energy dissipation with h_c/H for ramp slope 1V:3H for all gradations

3.2.2. Variation of Relative Energy Dissipation with Ramp Slope

Variation of relative energy dissipation with h_c/H for three ramp slopes for gradation G-1 is shown in the Fig. 9 as illustration. It is clear from the Fig. 9 that energy dissipation is high for low slope and vice-versa. This is due to fact that length of the ramp is more for low slope. However, relative energy dissipation per unit length of ramp increases with increase of ramp slopes as shown in Fig. 10.

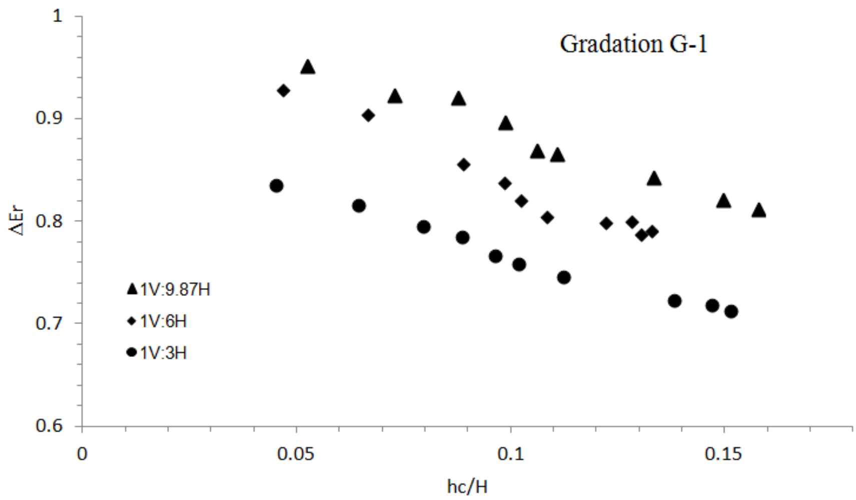
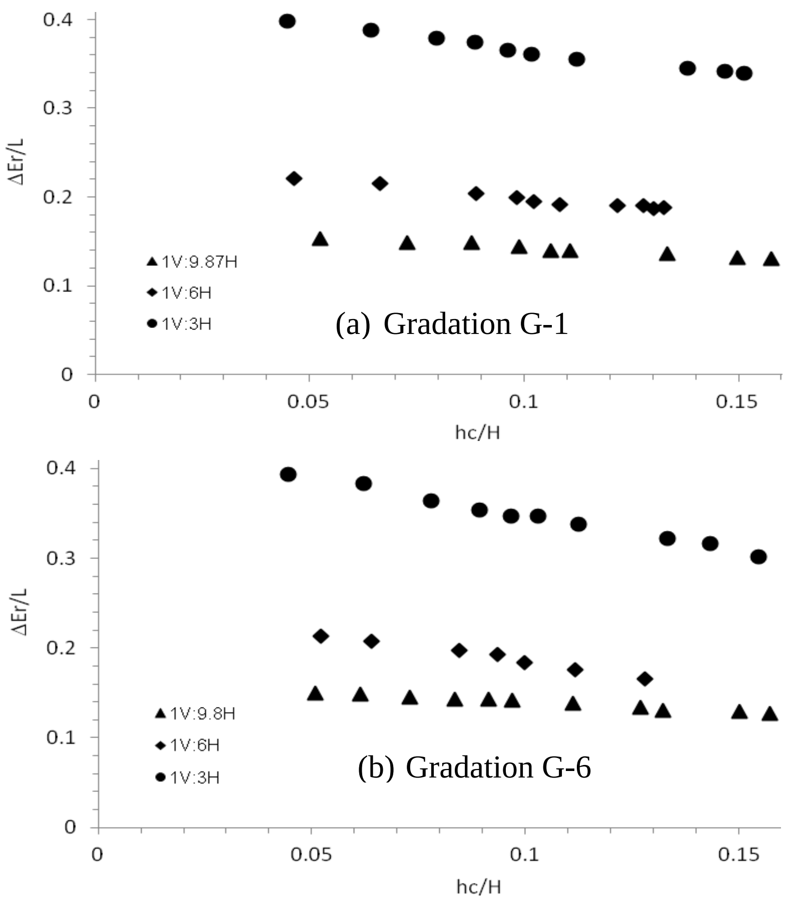


Figure 9 - Variation of energy dissipation with hc/H for gradation G-1 at different slopes



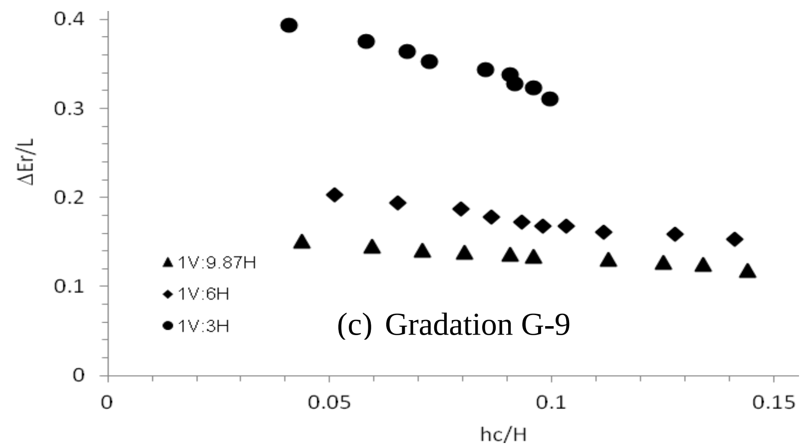


Figure 10 - Variation of energy dissipation per unit ramp length with h_c/H for three gradations

4. CONCLUSIONS

Experimental study on block ramp with macro roughness has been carried out in this paper for studying the water surface profile over the ramp and also for quantification of energy loss. Measured water surface profiles over ramps of slope 1/9.87; 1/6 and 1/3 for different discharges reveal that steeper slope is reigned mainly by non-uniform flow, however, uniform flow occurs on major part of the ramps for milder slopes. It has been observed that the energy dissipation over block ramp with large roughness is more for higher size of the boulder. The energy dissipation computed using Pagliara and Chiavaccini's (2006a) equation is in good agreement for low slope (1V:9.87H), while it deviates from the observed values for higher slopes (1V:6H) and (1V:3H). It is to be noted that for *S*=1/3, extrapolation is carried out for Pagliara and Chiavaccini's (2006a) equation out of its tested range. Energy dissipation per unit length of ramp increases with increase in the ramp slopes.

5. ACKNOWLEDGMENTS

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